DESCRIPTION

SURFACE ACOUSTIC WAVE SENSOR

Technical Field

The present invention relates to surface acoustic wave sensors such as biosensors and gas sensors. The present invention particularly relates to a surface acoustic wave sensor, using an SH-type surface acoustic wave, for detecting a target substance on the basis of the change in frequency due to the mass applied to the sensor.

Background Art

Various surface acoustic wave sensors including surface acoustic wave elements have been used to detect various substances. For example, a surface acoustic wave sensor for detecting biological substances such as DNAs and antibodies includes a reaction membrane, placed on a surface acoustic wave element, reacting only with a specific biological substance such as a DNA or an antibody. Such a DNA or antibody is bound to the reaction membrane by reaction; hence, a mass is applied to the surface acoustic wave element. The presence or content of the DNA or the antibody is detected on the basis of the change in frequency due to the

applied mass.

Japanese Unexamined Patent Application Publication No. 10-90270 discloses an example of this type of surface acoustic wave sensor. The surface acoustic wave sensor disclosed in this known document can detect 2-MIB (2-methylisoborneol) that is an earthy-smelling substance contained in water. With reference to Fig. 12, the surface acoustic wave sensor 101 includes interdigital transducers 103 and 104, a metal thin-film 105, and a piezoelectric substrate 102 on which the interdigital transducers 103 and 104 and the metal thin-film 105 are arranged. Amplifiers 106 and 107 are placed between one pair of the interdigital transducers 103 and the other pair of the interdigital transducers 104 and connected thereto. A mixer 108 is connected to rear portions of the interdigital transducers 104 for output and rear portions of the amplifiers 106 and 107. An output from the surface acoustic wave sensor 101 is extracted from the mixer 108.

In the surface acoustic wave sensor 101, a camphor-Ova complex is immobilized on the upper face of the piezoelectric substrate 102. The camphor-Ova complex functions as a reaction membrane; hence, 2-MIB is detected by the reaction between the camphor-Ova complex and 2-MIB.

That is, a complex antigen containing protein and camphor having a structure similar to that of 2-MIB, which is an earthy-smelling substance, is immobilized on the surface acoustic wave sensor 101. The surface acoustic wave sensor 101 is immersed in a test solution containing a certain amount of a 2-MIB antibody specifically bound to 2-MIB and the camphor-protein complex antigen competitively reacts with 2-MIB which is present in the solution and of which the content is unknown. The amount of the 2-MIB antibody bound to the camphor-protein complex antigen immobilized on the surface acoustic wave sensor 101 is determined from the change in output due to the mass applied to the surface acoustic wave sensor. The content of 2-MIB in the test solution is determined from the difference between the amount of the 2-MIB antibody bound to the camphor-protein complex antigen in the presence of 2-MIB and the amount of that in the absence of 2-MIB.

As described above, surface acoustic wave sensors have been widely used to detect or determine biological substances such as DNAs, antigens, and antibodies and various substances such as 2-MIB, which is a cause of earthy odor. This type of surface acoustic wave sensor includes a piezoelectric substrate and a reaction membrane,

placed thereon, suitable for a target substance.
The target substance is detected or determined from
the change in frequency due to the mass applied to
the reaction membrane.

In the surface acoustic wave sensor, the change
in mass is detected as the change in frequency.
Therefore, an increase in frequency change leads to
an increase in the sensitivity of the surface
acoustic wave sensor. In order to enhance the
sensitivity, reaction membranes suitable for target
substances have been widely investigated.

On the other hand, the relationship between the
sensitivity of the surface acoustic wave sensor and
the structure of a surface acoustic wave element
included in the surface acoustic wave sensor has
not been intensively investigated.

Disclosure of Invention

In view of the foregoing circumstances, it is
an object of the present invention to provide a
surface acoustic wave sensor which includes a
surface acoustic wave element with an improved
structure and which therefore has high sensitivity.
The surface acoustic wave sensor further includes a
reaction membrane placed on the surface acoustic
wave element and detects a target substance from
the change in the mass applied to the surface

acoustic wave element.

The present invention provides a surface acoustic wave sensor for detecting the minute mass applied to a surface acoustic wave element on the basis of the change in frequency using an SH-type surface acoustic wave. The surface acoustic wave sensor includes a rotated Y-cut $LiTaO_3$ substrate having Euler angles (0°, 0° to 18°, 0° ± 5°) or (0°, 58° to 180°, 0° ± 5°); electrodes, principally containing Au, for exciting a surface acoustic wave, the electrodes being arranged on the $LiTaO_3$ substrate; and a reaction membrane, bound to a target substance or a binding substance bound to the target substance, covering the electrodes arranged on the $LiTaO_3$ substrate. The electrodes have a normalized thickness of 0.8% to 9.5%, the normalized thickness being determined by normalizing the thickness of the electrodes by the wavelength of the surface acoustic wave.

The rotated Y-cut $LiTaO_3$ substrate preferably has Euler angles (0°, 120° to 140°, 0° ± 5°).

In a specific aspect of the present invention, the surface acoustic wave sensor further includes a bonding layer, placed between the reaction membrane and the electrodes, for enhancing the bond between the reaction membrane and the electrodes.

In another specific aspect of the present

invention, the surface acoustic wave sensor further includes a protective layer, placed between the reaction membrane and the electrodes, lying over the electrodes and regions outside the electrodes.

In another specific aspect of the present invention, the surface acoustic wave sensor further includes a protective layer, placed between the bonding layer and the electrodes, lying over the electrodes and regions outside the electrodes.

In another specific aspect of the present invention, the electrodes have a normalized thickness of 1.2% to 8.5%, the normalized thickness being determined by normalizing the thickness of the electrodes by the wavelength of the surface acoustic wave.

In another specific aspect of the present invention, the electrodes have a normalized thickness of 1.9% to 6.6%, the normalized thickness being determined by normalizing the thickness of the electrodes by the wavelength of the surface acoustic wave.

In another specific aspect of the present invention, the electrodes have a normalized thickness of 3.0% to 5.0%, the normalized thickness being determined by normalizing the thickness of the electrodes by the wavelength of the surface acoustic wave.

A biosensor according to the present invention includes the surface acoustic wave sensor. The reaction membrane contains a substance bound to a biological substance that is a target substance and the mass applied to a face of the substrate of the surface acoustic wave sensor is varied due to the bind of the biological substance to the reaction membrane.

Brief Description of the Drawings

Figs. 1(a) to 1(d) are illustrations showing the measurement principle of a surface acoustic wave sensor according to the present invention, Fig. 1(a) is a schematic front sectional view of the surface acoustic wave sensor immersed in liquid containing no target substance, Fig. 1(b) is an illustration showing the change in frequency measured in the liquid containing no target substance, Fig. 1(c) is a schematic front sectional view of the surface acoustic wave sensor immersed in liquid containing a target substance, and Fig. 1(d) is an illustration showing the change in frequency measured in the liquid containing the target substance.

Fig. 2 is a schematic plan view showing the electrode structure of a two-port type surface acoustic wave resonator prepared in Experiment 1.

Fig. 3 is a graph showing the initial
impedance-frequency response measured using a
Rayleigh wave, that measured using an SH wave, and
the impedance-frequency response after damping in
liquid.

Fig. 4 is a graph showing the time-dependent
change in frequency determined by applying a mass
to surface acoustic wave elements, prepared in an
experiment, including interdigital transducers
having different normalized thicknesses.

Fig. 5 is a graph showing the change in
frequency determined by applying a mass of 10
ng/cm^2 to surface acoustic wave elements, prepared
in Experiment 3, including interdigital transducers
having different normalized thicknesses.

Fig. 6 is a graph showing the relationship
between the change in frequency and the normalized
thickness of electrodes arranged on $LiTaO_3$
substrates having different Euler angles.

Fig. 7 is a graph showing the displacements U1,
U2, and U3 of a P wave, an SH wave, and an SV wave,
respectively, propagating on $LiTaO_3$ substrates
having Euler angles of which θ is varied.

Fig. 8 is a graph showing the relationship
between the insertion loss and frequency response
of a surface acoustic wave sensor, according to an
embodiment of the present invention, including a

two-port type surface acoustic wave resonant.

Figs. 9(a) and 9(b) are schematic front sectional views of modifications of a surface acoustic wave sensor, according to the present invention, including a protective layer.

Fig. 10 is a schematic plan view showing the electrode structure of a one-port type surface acoustic wave resonator that is an example of the electrode structure of a surface acoustic wave sensor according to the present invention.

Fig. 11 is a schematic plan view showing the electrode structure of a transversal surface acoustic wave filter that is another example of the electrode structure of a surface acoustic wave sensor according to the present invention.

Fig. 12 is a schematic plan view illustrating a known surface acoustic wave sensor.

Best Mode for Carrying Out the Invention

Embodiments of the present invention will now be described in detail with reference to the accompanying drawings. Features of the present invention will become apparent from the description.

Figs. 1(a) to 1(b) are illustrations showing the measurement principle of a surface acoustic wave sensor according to an embodiment of the present invention.

The surface acoustic wave sensor 1 of this
embodiment uses an SH-type surface acoustic wave
and includes a rotated Y-cut LiTaO$_3$ substrate 2
substrate having Euler angles (0°, 0° to 18°, 0° ±
5°) or (0°, 58° to 180°, 0° ± 5°). Interdigital
transducers 3 for exciting the surface acoustic
wave are arranged on the LiTaO$_3$ substrate 2. The
interdigital transducers 3 are made of Au. The
interdigital transducers 3 have a normalized
thickness of 0.8% to 9.5%, the normalized thickness
being determined by normalizing the thickness of
the interdigital transducers 3 by the wavelength of
the surface acoustic wave.

A reaction membrane 4 is placed on the LiTaO$_3$
substrate 2. The reaction membrane 4 may be made
of a material bound to a target substance or a
binding substance bound to such a target substance.

When the surface acoustic wave sensor 1 is
immersed in a liquid 5 containing no target
substance, the liquid 5 contacts the reaction
membrane 4 as shown in Fig. 1(a). In this
situation, although no target substance is present
in the liquid 5, the liquid 5 contacts the reaction
membrane 4; hence, a mass is applied to a face of
the LiTaO$_3$ substrate 2 on which the interdigital
transducers 3 are arranged. Therefore, as shown in
Fig. 1(b), the frequency response A of the surface

acoustic wave sensor 1 free from the liquid 5 is shifted to the frequency response B of the surface acoustic wave sensor 1 immersed in the liquid 5, that is, the frequency is reduced. The reduction of the frequency is relatively small.

On the other hand, when the surface acoustic wave sensor 1 is immersed in the liquid 5 containing a target substance 6, the target substance 6 is bound to the reaction membrane 4 as shown in Fig. 1(c). Therefore, the mass of the target substance 6 is applied to the substrate face having the interdigital transducers 3 arranged thereon in addition to the effect of the liquid 5.

The target substance 6 contained in the liquid 5 reacts with the reaction membrane 4 and is bound to the reaction membrane 4. The SH-type surface acoustic wave excited on the $LiTaO_3$ substrate 2 is greatly affected by the mass of the target substance 6; therefore, the presence of the target substance can be detected from the change in frequency as described above.

The surface acoustic wave sensor 1 is characterized in that the surface acoustic wave sensor 1 uses the SH-type surface acoustic wave and includes the rotated Y-cut $LiTaO_3$ substrate 2 having the above Euler angles and the interdigital transducers 3 are made of Au and have a normalized

thickness of 0.8% to 9.5%, the normalized thickness being determined by normalizing the thickness of the interdigital transducers 3 by the wavelength of the surface acoustic wave. As is clear from experiments below, the surface acoustic wave sensor 1 has high sensitivity due to the above configuration. This will now be described with reference to the experiments.

[Experiment 1]

Two-port type surface acoustic wave resonators were each prepared in such a manner that a 36°-rotated Y-cut LiTaO$_3$ substrate was prepared and an interdigital transducer and reflectors were formed on the LiTaO$_3$ substrate, the reflectors being arranged on both sides of the interdigital transducer in the direction of the propagation of a surface acoustic wave. The resonator had no reaction membrane.

One of the surface acoustic wave sensors that included the following interdigital transducer was measured for frequency response: an interdigital transducer having a normalized thickness of about 2%, the normalized thickness being determined by normalizing the thickness of the electrodes by the wavelength of the surface acoustic wave. With reference to Fig. 3, the solid lines indicate the impedance-frequency response of the surface

acoustic wave sensor in an initial state and the phase-frequency response thereof.

With reference to Fig. 3, Arrow X1 indicates resonances associated with a Rayleigh wave and Arrow X2 indicates resonances associated with an SH-type surface acoustic wave.

With reference to Fig. 3, the broken lines indicate the impedance-frequency response of the surface acoustic wave sensor immersed in ethanol and the phase-frequency response thereof. As is clear from the comparison between the responses indicated by the solid lines and those indicated by the broken lines, for the resonances X1 associated with the Rayleigh wave, the excitation in liquid is weak; however, for the resonances X2 associated with the SH-type surface acoustic wave, the excitation is not weak. That is, the Rayleigh wave is useless for the sensor immersed in liquid. Therefore, the surface acoustic wave sensor can function well using the SH-type surface acoustic wave even if the surface acoustic wave sensor is immersed in liquid.

Therefore, according to the present invention, the surface acoustic wave sensor uses the response of the SH-type surface acoustic wave.

Fig. 7 is a graph showing the displacement of surface acoustic waves propagating on $LiTaO_3$

substrates having different Euler angles (0°, θ, 0°), θ (degrees) being varied. In this figure, the vertical axis represents the displacement in a normalized form. With reference to Fig. 7, the dotted-chain line indicates the displacement U2 of the SH wave used herein, the solid line indicates the displacement U1 of a P wave, and the broken line indicates the displacement U3 of an SV wave.

As is clear from Fig. 7, when θ of the Euler angles is in the range of 0° to 18° or 58° to 180°, the displacement U2 of the SH wave is large and constant and the SH wave is principally excited. When the sensor is immersed in liquid as described above, the resonances associated with the Rayleigh wave are weak but the resonances associated with the SH-type surface acoustic wave are not exceedingly weak. Therefore, when the $LiTaO_3$ substrate has Euler angles of which θ is in the range of 0° to 18° or 58° to 180°, the SH wave can be sufficiently excited if the surface acoustic wave sensors are immersed in liquid.

Furthermore, when θ of the Euler angles is in the range of 120° to 140°, the displacement U3 of the resonance associated with the SV wave that is present close to the resonance associated with the SH wave is small. Therefore, θ of the Euler angles is preferably in the range of 120° to 140°. This

can effectively prevent the deterioration of the
frequency response of the surface acoustic wave
sensors immersed in liquid because the influence of
the SV wave is not large.

Therefore, according to the present invention,
the $LiTaO_3$ substrates preferably have Euler angles
of which θ is in the range of 0° to 18° or 58° to
180° and more preferably 120° to 140°. This allows
the sensors to function well using the SH wave if
the sensors are immersed in liquid.

Although it is necessary that θ of the Euler
angles is in the range of 0° to 18° or 58° to 180°,
the same advantages as described above can be
achieved when the Euler angles are in the range of
(0°, 0° to 18°, 0° ± 5°) or (0°, 58° to 180°, 0° ±
5°).

[Experiment 2]

Three types of surface acoustic wave sensors
including no reaction membranes were prepared in
the same manner as that described in Experiment 1
except that interdigital transducers made of Au had
a normalized thickness of 0.4%, 2.0%, or 5.5%. Fig.
8 shows the frequency response of a surface
acoustic wave sensor including an interdigital
transducer having a normalized thickness of 2.0%.
The three types of surface acoustic wave sensors
were immersed in ethanol and alkanethiol was added

dropwise to the ethanol such that the concentration thereof was 140 μmol/l.

The alkanethiol used was 10-carboxy-1-decanethiol-COOH-$(CH_2)_{10}$-SH.

The terminal S atom of the alkanethiol reacts with Au contained in the electrodes, whereby a self-assembled monolayer is formed on each Au electrode. The mass of the self-assembled monolayer is applied to the electrode; hence, the frequency response of the surface acoustic wave sensors is varied as well as that of those surface acoustic wave sensors 1 of the above embodiment.

As a result of the reaction of the alkanethiol with Au contained in the interdigital transducers, the self-assembled monolayers were formed. The frequency response of the surface acoustic wave sensors was varied by the effect of the mass of the self-assembled monolayers. Fig. 4 shows the results. In Fig. 4, the horizontal axis represents the time (minute) elapsed from the dropwise addition of the alkanethiol and the vertical axis represents the change (kHz) in the resonance frequency of an SH-type surface acoustic wave.

As is clear from Fig. 4, for the electrode with a normalized thickness of 0.4%, the frequency is decreased by 20 kHz after about 40 minutes elapsed from the dropwise addition of the alkanethiol. On

the other hand, for the electrodes with a normalized thickness of 2.0% or 5.5%, the frequency is decreased by 40 kHz after about 40 minutes elapsed from the dropwise addition of the alkanethiol. This shows that the variation in the normalized thickness of the electrodes leads to the change in the frequency of the surface acoustic wave sensors.

The self-assembled monolayers made of the alkanethiol are tightly bonded to the interdigital transducers, made of Au, for exciting surface acoustic waves. Therefore, the self-assembled monolayers are preferably used as bonding layers according to the present invention. The use of the self-assembled monolayers effectively enhances the bond between the interdigital transducers and the reaction membranes placed on the bonding layers. This leads to the enhancement in the reliability of the surface acoustic wave sensors; hence, the change in the mass applied to the reaction membranes can be precisely measured.

A material for forming the bonding layers is not limited to the alkanethiol and any alkanethiol derivative or another compound may be used. Any compound bound to the $LiTaO_3$ substrates and the electrodes for exciting surface acoustic waves can be used.

[Experiment 3]

In consideration of the results of Experiment 2, surface acoustic wave sensors were measured for change in frequency due to the mass of the alkanethiol by varying the normalized thickness of electrodes in the range of 0% to 10% in the same manner as that described in Experiment 2. Fig. 5 shows the measurement results.

As is clear from Fig. 5, for the electrodes with a normalized thickness of 0.8% to 9.5%, the change in frequency is 30 ppm or more. A frequency change of 30 ppm is substantially equal to the change in frequency due to a temperature change of 0.9°C. Hence, the electrodes with a normalized thickness of 0.8% to 9.5% can cope with a temperature change of less than 0.9°C. In other words, even if the temperature changes by less than 0.9°C, the change in frequency is greater than the difference in frequency due to the change in temperature; hence, the change in frequency can be securely detected.

For the electrodes with a normalized thickness of 1.2% to 8.5%, the change in frequency is 35 ppm or more. The change in temperature that causes a frequency change of 35 ppm is 1°C. Therefore, if the electrodes have a normalized thickness of 1.2% to 8.5%, the surface acoustic wave sensors can cope

with a temperature change of 1°C.

For the electrodes with a normalized thickness of 1.9% to 6.6% or 3% to 5%, the change in frequency is 45 ppm or more or 55 ppm or more, respectively. The change in temperature that causes a frequency change of 45 ppm is 1.3°C and the change in temperature that causes a frequency change of 55 ppm is 1.6°C. When the electrodes have a normalized thickness of 1.9% to 6.6% and preferably 3% to 5%, the surface acoustic wave sensors including these electrodes can function well even if the temperature changes by 1.3°C and 1.6°C, respectively.

That is, if the change in temperature causes a change in frequency, the surface acoustic wave sensors can function well because these electrodes have a normalized thickness in the above range.

[Experiment 4]

In Experiment 1, the 36°-rotated Y-cut $LiTaO_3$ substrate, that is, the rotated Y-cut $LiTaO_3$ substrate having Euler angles (0°, 126°, 0°) was used. In Experiment 4, $LiTaO_3$ substrates having different Euler angles and normalized thicknesses were prepared and various surface acoustic wave elements including such substrates were prepared. The surface acoustic wave elements were measured for change in frequency due to the mass applied

thereto in the same manner as that described in Experiment 1. Fig. 6 shows the measurement results.

The surface acoustic wave elements have substantially the same configuration as that of the surface acoustic wave resonators prepared in Experiment 2 except that the Euler angles of the $LiTaO_3$ substrates were varied.

Fig. 6 shows the displacement of these surface acoustic wave elements including the $LiTaO_3$ substrates in which θ of Euler angles is varied. As is clear from Fig. 6, the variation in Euler angles does not significantly change the relationship between the normalized thickness and the change in frequency. Therefore, the $LiTaO_3$ substrates may have Euler angles sufficient to excite an SH wave.

As is clear from Experiments 1 to 4 described above, when an electrode, principally containing Au, for exciting a surface acoustic wave is placed on a $LiTaO_3$ substrate which have Euler angles ($0°$, $0°$ to $18°$, $0° \pm 5°$) or ($0°$, $58°$ to $180°$, $0° \pm 5°$) and which have a normalized thickness of 0.8% to 9.5%, the change in frequency due to the mass applied thereto can be precisely measured using the response of an SH wave. Therefore, according to the present invention, a target substance can be precisely detected or determined using a surface

acoustic wave element having the above configuration and a reaction membrane 4 (see Fig. 1) placed on the surface acoustic wave element.

The reaction membrane is not particularly limited and any reaction membrane suitable to detect a target substance may be used. For example, the following reaction membrane may be used when 2-MIB which is a cause of earthy odor is detected: a reaction membrane containing the camphor-protein complex having a structure similar to that of 2-MIB as disclosed in Japanese Unexamined Patent Application Publication No. 10-90270. Alternatively, when a specific DNA, antigen, or antibody is detected, any reaction membrane containing a substance specifically bound to such a DNA, antigen, or antibody can be used.

The reaction membrane need not necessarily react with a target substance to be bound to the target substance but may react with a bonding substance bound to the target substance.

A specific embodiment of the present invention provides a biosensor in which the reaction membrane contains a substance that can be bound to a biological substance such as a DNA, an antigen, or an antibody and in which the mass applied to a face of a substrate included in a surface acoustic wave sensor is varied due to the bind of the biological

substance to the reaction membrane. Therefore, the biological substance can be precisely detected or determined using the biosensor.

As schematically shown in Fig. 9(a), it is preferable that a protective layer 7 cover interdigital transducers 3 arranged on a $LiTaO_3$ substrate 2 and a bonding layer 8 and a reaction membrane 4 be deposited on the protective layer 7 in that order. Since the protective layer 7 is placed between the bonding layer 8 and the interdigital transducers 3, the interdigital transducers 3 and the $LiTaO_3$ substrate 2 can be protected. When the protective layer 7 is made of an insulating material such as SiO_2, an undesired short circuit can be prevented from occurring even if a surface acoustic wave sensor is immersed in an electrically conductive liquid. The protective layer 7 also lies over regions outside the interdigital transducers 3; hence, the bonding layer 8 can be formed over the protective layer 7. This leads to an enhancement in the sensitivity of the sensor.

When the protective layer 7 is made of SiO_2 or another material, a material for forming the bonding layer 8 is not an alkanethiol but preferably a methoxysilane such as $(CH_3O)_3SiC_3H_6OCH_2CHCH_2O$. This is because the methoxy

group CH_3O is superior in affinity to an inorganic compound such as SiO_2.

With reference to Fig. 9(a), the protective layer 7 is placed between the bonding layer 8 and the interdigital transducers 3. However, as shown in Fig. 9(b), a surface acoustic wave device including no bonding layer 8 may include a protective layer 7. In the surface acoustic wave device shown in Fig. 9(b), this protective layer 7 is placed between a reaction membrane 4 and interdigital transducers 3. In the device, when this protective layer is made of an insulating material such as SiO_2, an undesired short circuit can be prevented from occurring between these interdigital transducers 3. Since this protective layer 7 lies over not only the interdigital transducers 3 but also regions outside these interdigital transducers 3, this reaction membrane 4 can be formed over this protective layer 7. This leads to an enhancement in the sensitivity of the device.

In order to detect a target substance using a surface acoustic wave sensor according to the present invention, a surface acoustic wave device which has substantially the same configuration as that of the surface acoustic wave sensor except that the device includes no reaction membrane may

be used as a reference. In this case, the change in frequency due to immersion in liquid can be neglected by determining the difference between the change in frequency due to the immersion of the surface acoustic wave sensor in liquid and the change in frequency due to the immersion of the surface acoustic wave device in liquid; hence, only the change in frequency due to the bind of the target substance or the bonding substance to a reaction membrane can be precisely measured.

In the surface acoustic wave sensor, the shape of an electrode, included in a surface acoustic wave element, for exciting a surface acoustic wave is not particularly limited. As shown in Fig. 10, the electrode may be configured such that a one-port type surface acoustic wave resonator including an interdigital transducer 21 and reflectors 22 and 23 can be obtained. Alternatively, as shown in Fig. 11, a transversal surface acoustic wave filter 30 including the following electrodes may be configured: interdigital transducers 31 and 32 arranged in the direction of the propagation of a surface acoustic wave. The transversal surface acoustic wave filter 30 may further include a metal thin-film 33 placed between the interdigital transducers 31 and 32 as necessary.

Industrial Applicability

A surface acoustic wave sensor according to the present invention uses an SH-type surface acoustic wave and includes a surface acoustic wave element which includes a rotated Y-cut $LiTaO_3$ substrate having Euler angles (0°, 0° to 15°, 0° ± 5°) or (0°, 58° to 180°, 0° ± 5°) and which includes electrodes, having a normalized thickness of 0.8% to 9.5%, for exciting the surface acoustic wave, the electrodes being arranged on the $LiTaO_3$ substrate, the normalized thickness being determined by normalizing the thickness of the electrodes by the wavelength thereof. Hence, the change in frequency response due to the change in mass applied to the $LiTaO_3$ substrate can be precisely detected. Furthermore, since the surface acoustic wave sensor further includes a reaction membrane covering the electrodes arranged on the $LiTaO_3$ substrate, the change in frequency response can be precisely detected on the basis of the change in mass due to the bind of a target substance to the reaction membrane by reaction or the bind of the binding substance, which is bound to the target substance, to the reaction membrane. Therefore, surface acoustic wave sensors including various reaction membranes suitable for target substances can be greatly enhanced in sensitivity by improving the

structure of surface acoustic wave elements.

It has been attempted to enhance the sensitivity of known surface acoustic wave sensors by improving reaction membranes. In the present invention, the sensitivity of the surface acoustic wave sensor can be enhanced by improving the structure of the surface acoustic wave element including the reaction membrane.

The electrodes principally contain Au, which hardly reacts with other substances. Hence, the surface acoustic wave sensor hardly becomes dirty and properties thereof hardly deteriorate with time.

When a bonding layer for enhancing the bond between the reaction membrane and the electrodes is placed between the reaction membrane and the electrodes, the surface acoustic wave sensor has high reliability and the mass applied to the reaction membrane can be precisely detected.

Furthermore, when a protective layer made of an insulating material is placed between the electrodes and the reaction membrane or the bonding layer, an undesired short circuit can be prevented from occurring in the surface acoustic wave sensor immersed in a conductive liquid. The protective layer lies over the electrodes and regions outside the electrodes; hence, the reaction membrane and/or the bonding layer can be formed over the protective

layer. This leads to an enhancement in sensitivity.

When the bonding layer is made of alkanethiol, the bonding layer is tightly bonded to the electrodes made of Au, whereby a self-assembled monolayer is formed. Therefore, when the reaction membrane is placed on the bonding layer, the reaction membrane can be tightly bonded to the surface acoustic wave element.

When the electrodes have a normalized thickness of 1.2% to 8.5%, preferably 1.9% to 6.6%, and more preferably 3.0% to 5.0%, the surface acoustic wave sensor has particularly high sensitivity.

Since a biosensor according to the present invention includes the surface acoustic wave device according to the present invention, the reaction membrane contains a substance specifically bound to a biological substance that is a target substance; hence, the mass applied to the substrate of the surface acoustic wave sensor is varied due to the bind of the biological substance to the reaction membrane. Accordingly, the biological substance can be precisely detected or determined with the biosensor of the present invention.